Aircraft Capability Management

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Primary Messages

- Managing non-normals currently requires pilots to reason about poorly understood airplane systems; they won't do this well and new airplanes will make it harder
- Performance can be improved by using an automated agent to translate failures in system components to descriptions of airplane capabilities
- Automation can perform tasks that humans do poorly, and also help the flight crew get to better decisions
- As autonomous agents are developed to support these operational tasks, we need to ensure that those agents are effective team members

Acknowledgment:
Lars Fucke and Jelmer Reitsma of Boeing (Madrid)

Explosion of Alert Messages

Qantas A380 Uncontained Engine Failure

- QF 32; Singapore to Sydney; 469 people on board
- 4 minutes after Take-off, engine no. 2 bursts, severely damaging other equipment
- 43 ECAM messages in first 60 seconds; 10 additional later
- 50 minutes to sort through the non-normal checklists (NNCs)

"It was hard to work out a list of what had failed; it was getting to be too much to follow. So we inverted our logic: Instead of worrying about what failed, I said 'Let's look at what's working.'" *A380 Captain*

What is a Capability?

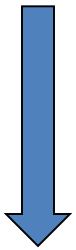
Airplane System Components

- Hydraulic system
- Thrust Reverser
- Battery
- Air conditioning pack

Airplane Capabilities

- Range / Endurance
- Stopping Distance (on runway)
- Ability to perform a specific approach
- Ability to enter RVSM airspace
- Maneuver envelope

Airplane system components have failed

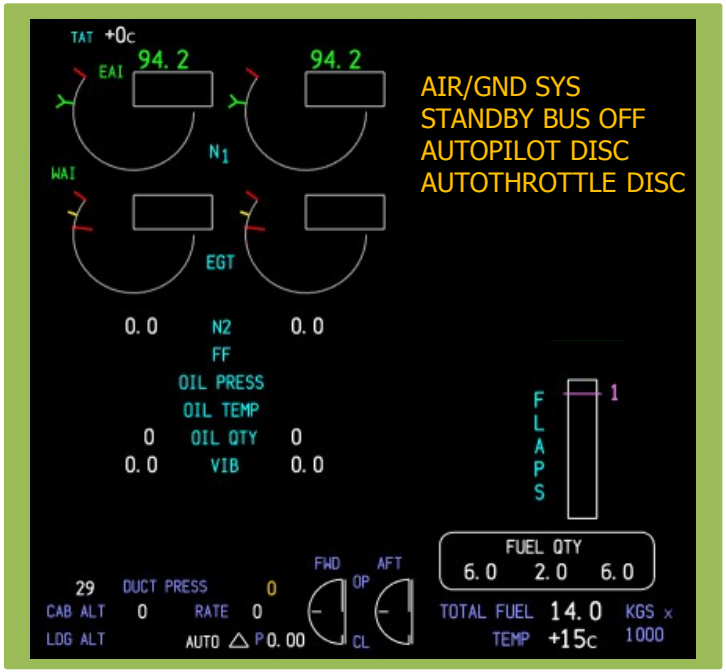


What can I do?
Where can I go?

757 Bus Failure

AAL Flight #268; SEA to JFK
September 22, 2008

- En route (CRZ); got several EICAS messages
- Performing STANDBY BUS OFF; initial action had them turn standby power selector to BAT (battery); they ended the checklist at that point
- A light showed that the battery was discharging but they couldn't determine how to change that situation
- They put the hot battery bus, battery bus, standby AC bus and standby DC bus all on the battery, which was no longer charging.



2 hr, 24 min later, battery power depleted, resulting in these effects (plus others)

- Captain's displays blanked
- PA failed
- Elevator trim systems failed
- Thrust reversers and spoilers failed to deploy automatically on landing
- Could not shut down the engines with fuel cutoff

None of these effects was expected by the flight crew!!

What Airplane Capabilities were Affected?

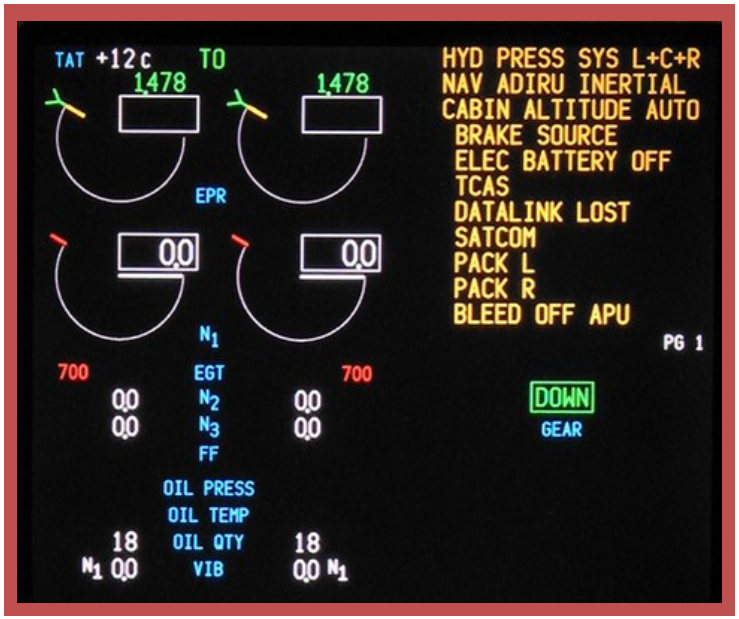
What systems are powered by those buses?

How do those systems affect airplane capabilities?

- Range
- Landing Distance
- Ice Protection
- Communication (with cabin)
- Maneuver Envelope
- Fire Detection and Extinguishing

Explicit Alerting on Capabilities

Typically, we don't



Can I Fly?

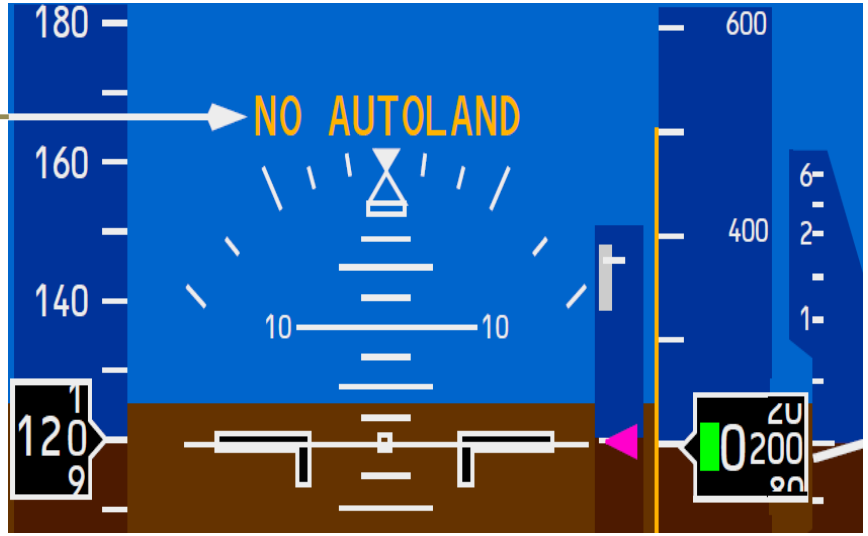
- 787
  - 449 EICAS messages (Warning, Caution, Advisory)
  - All but 19 of them reflect physical system failures/ status changes

Explicit Alerting on Capabilities

Sometimes, we do . . . .

Examples from the 787

- NO AUTOLAND
- NO LAND 3
- NAV UNABLE RNP
- STALL PROTECTION



The New Generation of Systems is Different

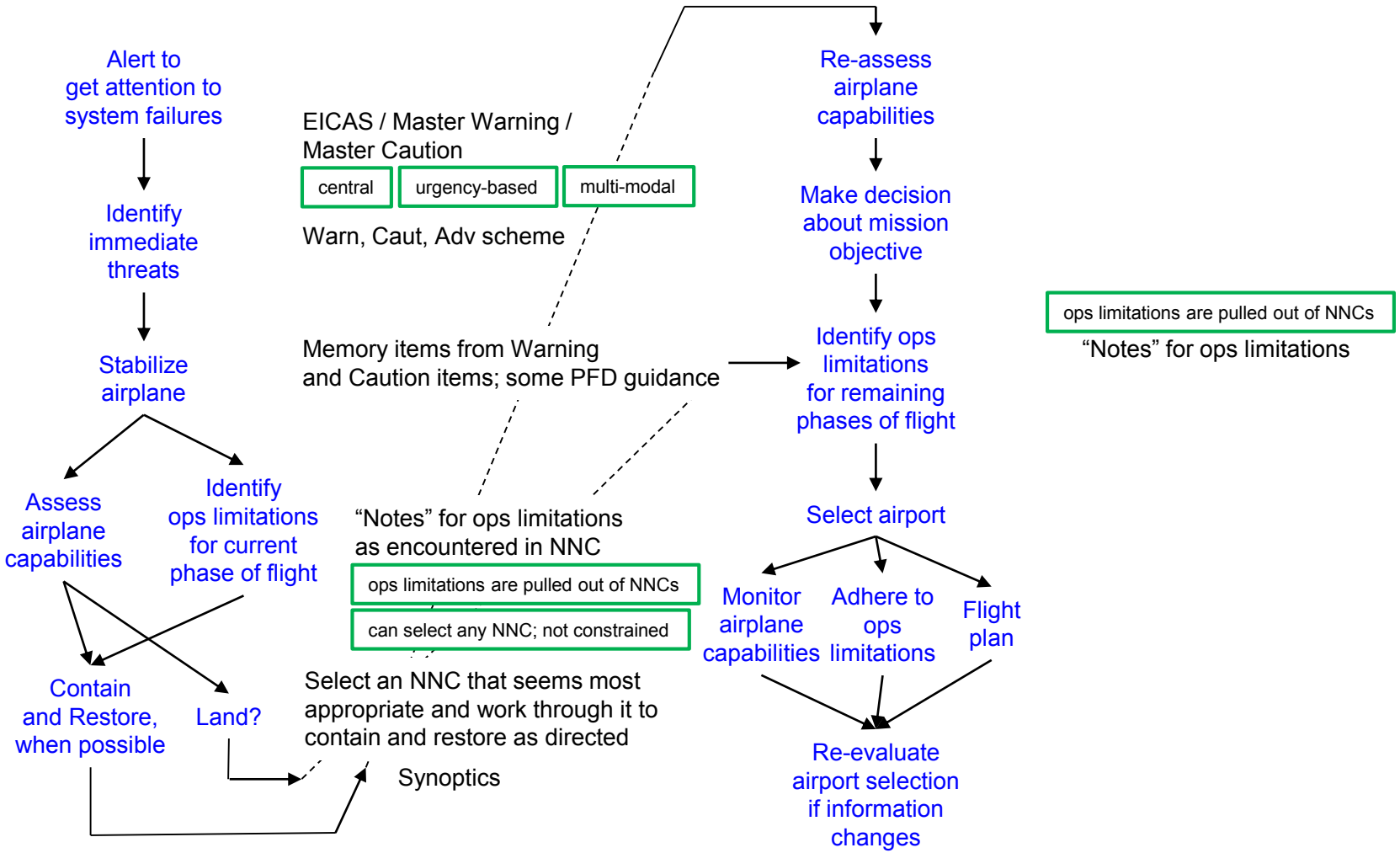
So are the pilots . . . .

Airplane System Integration  Pilot System Knowledge 

- Airplanes have become more integrated–more shared resources, more interconnections–and failures can have effects that are difficult to anticipate or understand
- The volume and rate of crew alert and status messages can increase significantly for certain types of failures
- Non-normal procedure design for combinations of failures is challenging
- Air turnbacks or diversions occur due to confusion about severity of the failures, and impact on the mission

<u>Both types of errors occur:</u>
- Poor understanding of real problems
- Oversensitivity to trivial changes

Managing a Non-normal (airplane system failure)



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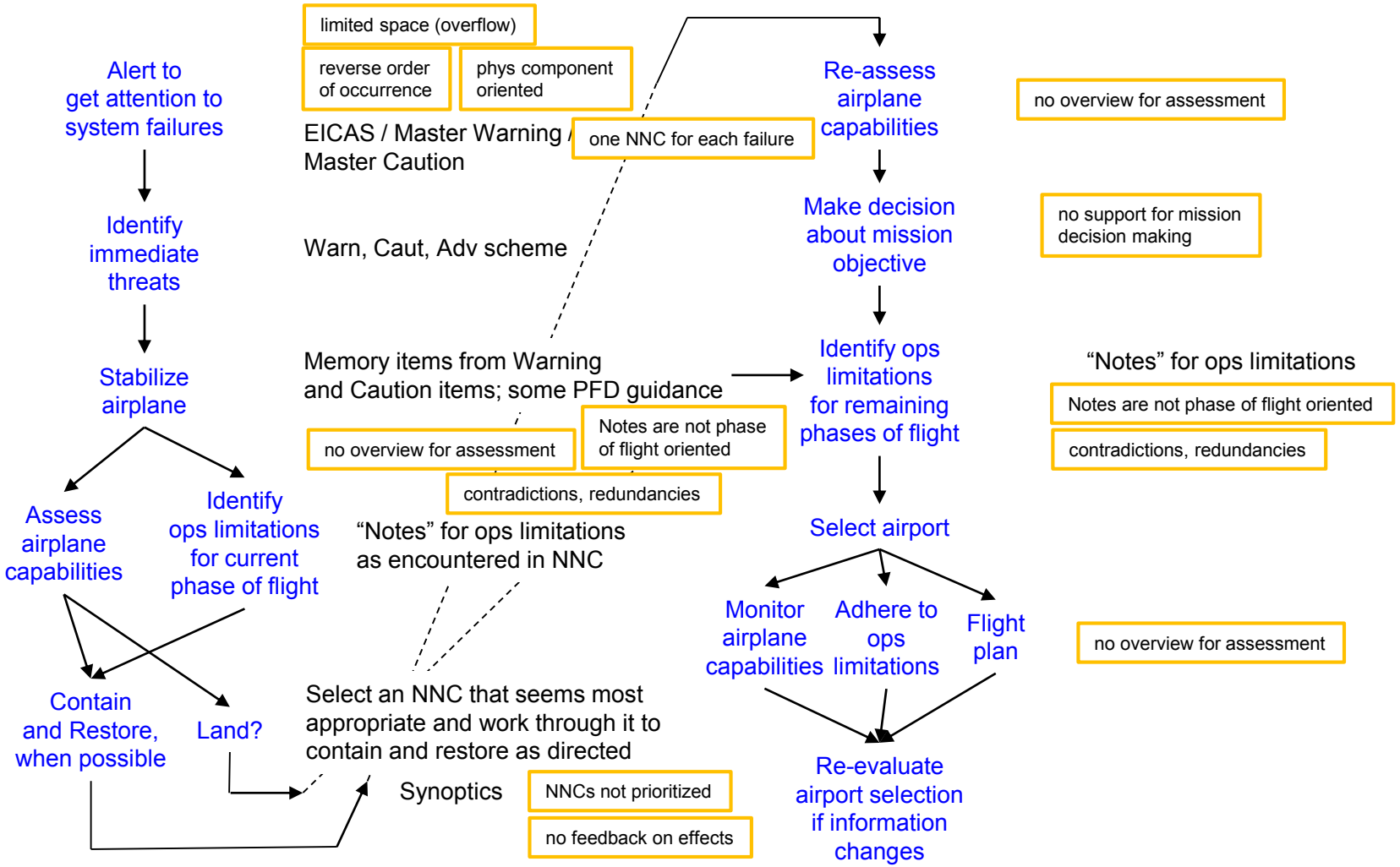
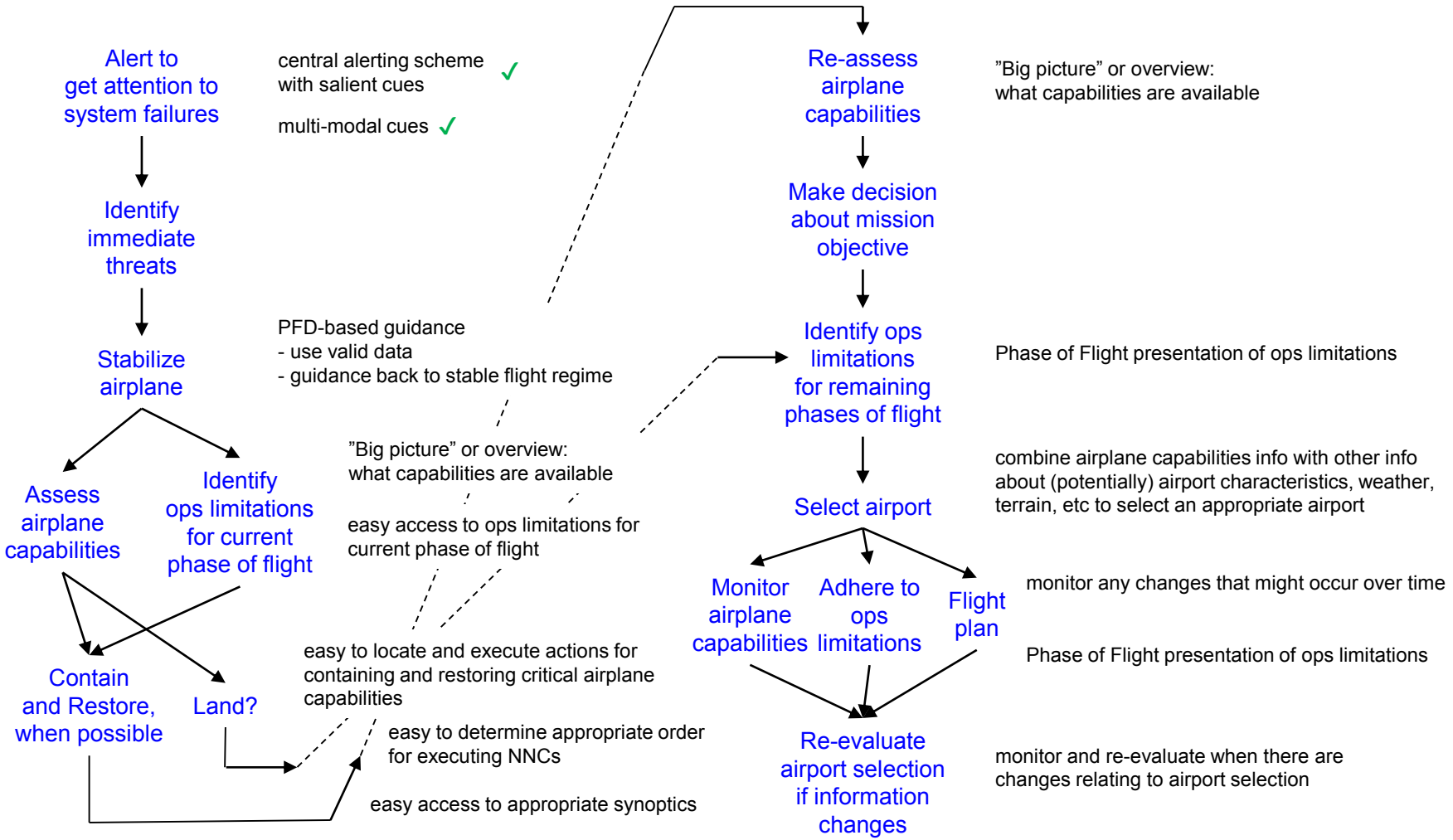


Managing a Non-normal: Better Support



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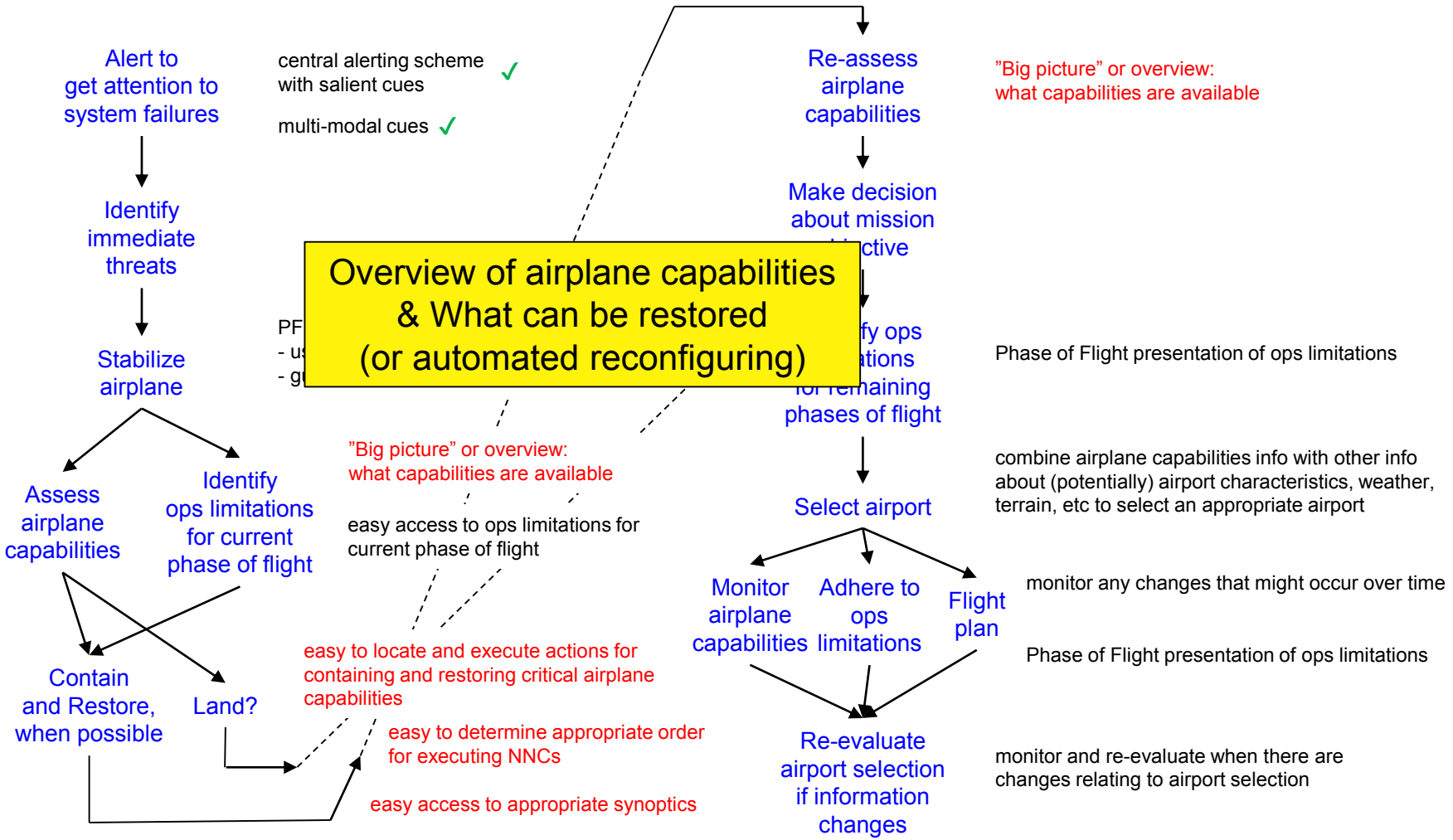

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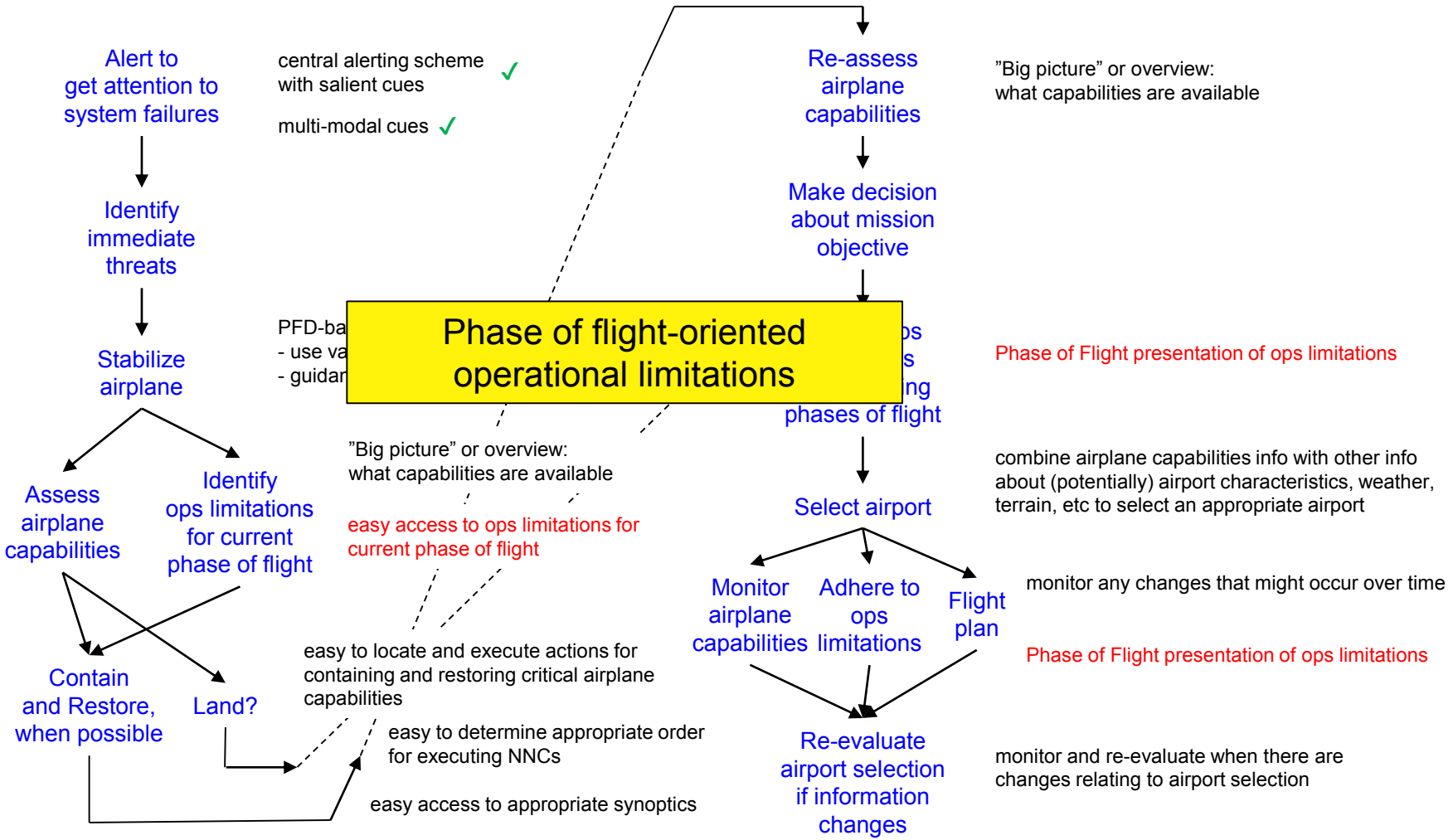

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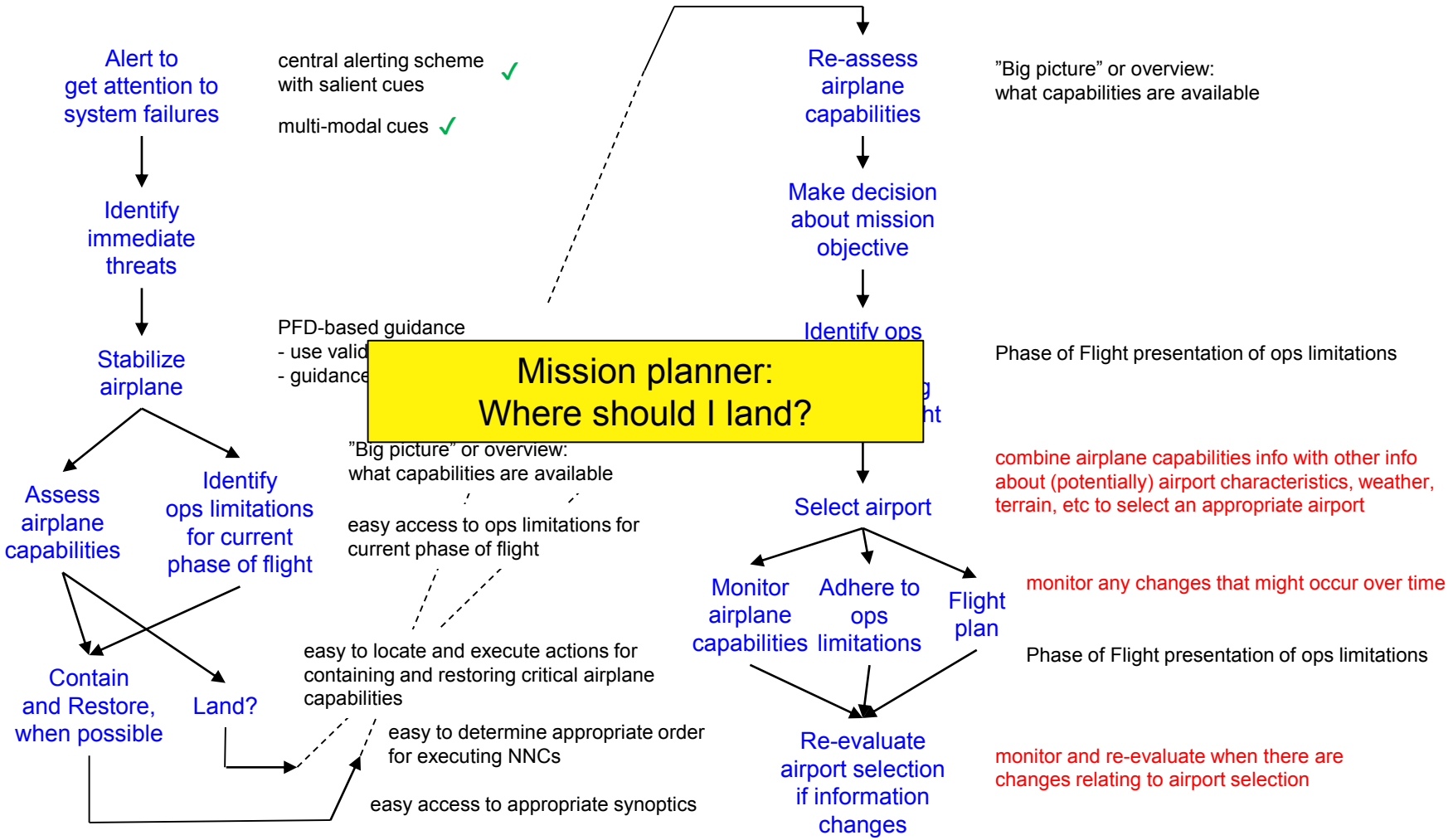


Three Types of Information for the Pilot

Answering Basic Questions

- **Status of Airplane Capabilities**
  - What is working/what is not?
  - How can I restore what has been lost?
- **Operational Guidance**
  - Which limitations do I need to observe during the remainder of the mission?
- **Mission Planner**
  - Can I still complete the planned mission?
  - If not, where else can I land?

Initial Ideas about Airplane Capabilities

Can I Take–off?
Can I reach my planned destination?
Can I land?
Envelope

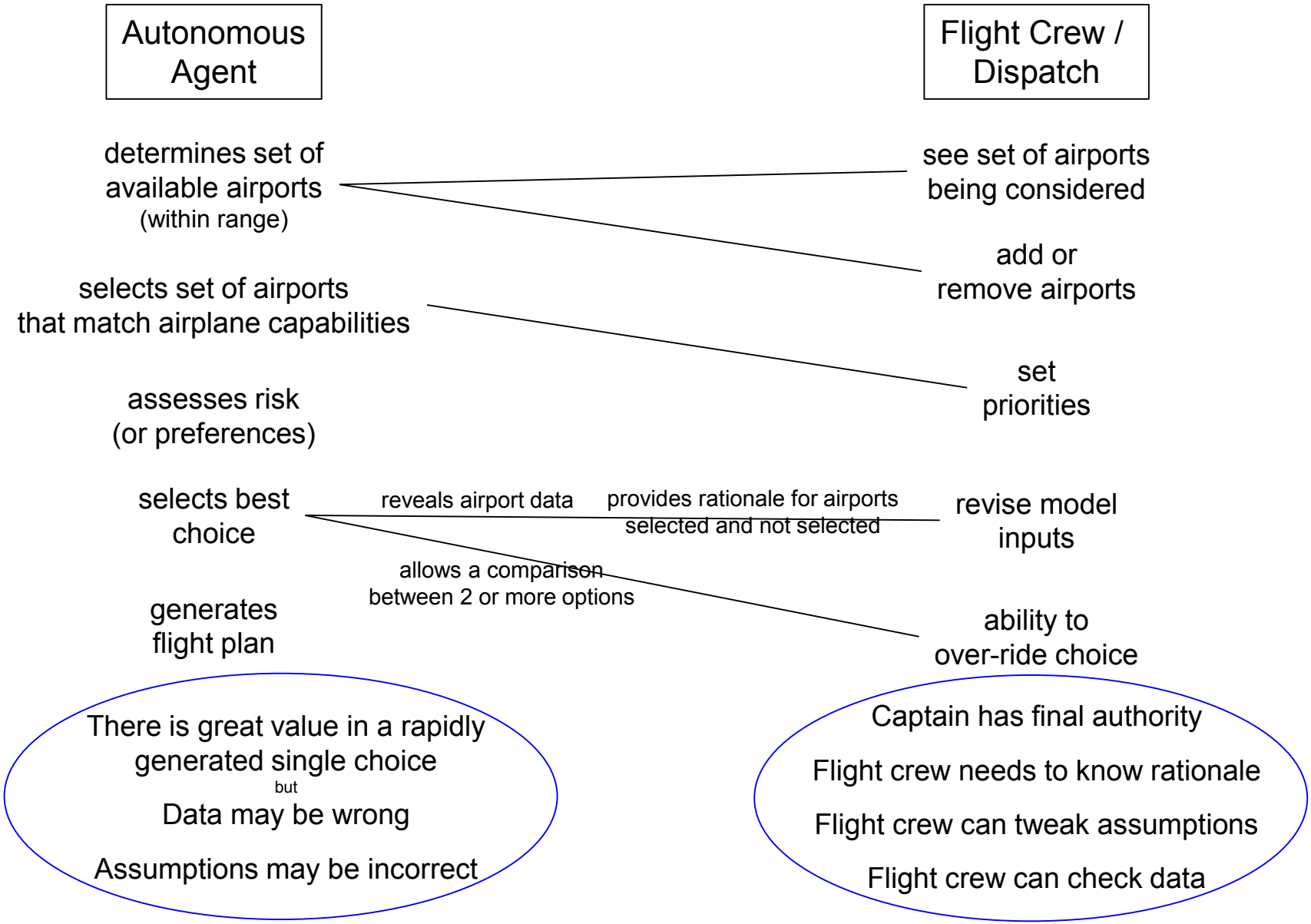
<u>Resources</u>
Electric Power
Hydraulic Power
Pneumatic Power
Equipment Cooling

Engines (state)

Navigation
Communication
Autoflight
Envelope Protection
Stability Augmentation
Cabin/Cargo Environment
Ice Protection
Fire Detection & Extinguishing
Airspace Access
Approach Access
Landing Distance
Runway Directional Control

<u>Additional Features:</u>
NNC Prioritization
Time to fail (or to recover)
System synoptics (to assess configuration changes)

Mission Decision: Where Should I Land?



Mission Decision: Where Should I Land?

from Emergency Landing Planner

maneuver envelope

weather

terrain

ceiling & visibility

available instrument approaches

medical resources nearby

winds

population exposure

runway conditions

runway length and width

emergency equipment

Mission Decision: Where Should I Land?

from ACM

estimate of range/ endurance

maneuver envelope

maneuver envelope

from Emergency Landing Planner

airspace restrictions

weather

terrain

operational limitations

limitations on landing performance (e.g., cross wind)

ceiling & visibility

available instrument approaches

the types of approaches that can be performed

medical resources nearby

estimate of required landing distance

winds

population exposure

runway conditions

emergency equipment

runway length and width

Lessons for Human-Autonomy Teaming

- Use autonomous agents to pull together information relevant to managing non-normals (information that humans cannot develop); e.g.,
  - changes to airplane capabilities
  - airport information, airplane compatibility
- Organize it in a way to benefit flight crew decision making
- Develop interface design requirements for an autonomous advisor and a negotiation approach so that the humans can add value

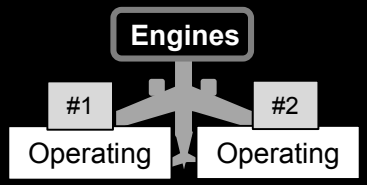
Planned Activities

- Develop a “framework/language” for communicating airplane capabilities
  - Pilot interviews and prototyping
- Develop a set of failure cases
- Develop system models to simulate system failures
- Collaborate with industry (e.g. SAA with Boeing)


Thank you

Rev 4

Status of Operational Capabilities



Can I Take-Off?	Envelope	Can I Reach Planned Destination?	Can I Land?
XX Config	Airspeed Gs Temp Max Altitude FL250	KLAX KLAX may be out of range Land at Nearest Suitable Airport	Gear Weight

Resources

- Electric Power — Load Shed
- Hydraulic Power
- Pneumatic Power
- Equipment Cooling

- Navigation
- Communication
- Autoflight
- Envelope Protection
- Stability Augmentation
- Cabin/Cargo Environment
- Ice Protection
- Fire Detection & Extinguishing
- Airspace Access
- Approach Access
- Landing Distance
- Directional Control Runway

Airspac
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RVS
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RLATSI
M
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x
Approache
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RNAV / GPS Approaches
ILS Approaches: CAT I / II / III
LOC Only Approaches

Phase of Flight Operational Limitations (for continued safe flight and landing)

Start / Taxi	Take-Off	Climb	Cruise	Descent	Approach	Land	Go Around	Taxi / Shut down

Current Cruise

Next Descent

Non-normal CL name:
operational limitation A
operational limitation B

Land

Start / Taxi | Take-Off | Climb | Cruise | Descent | Approach | Land | Go Around | Taxi / Shut down

ETOPS

Planned Dest: KSFO

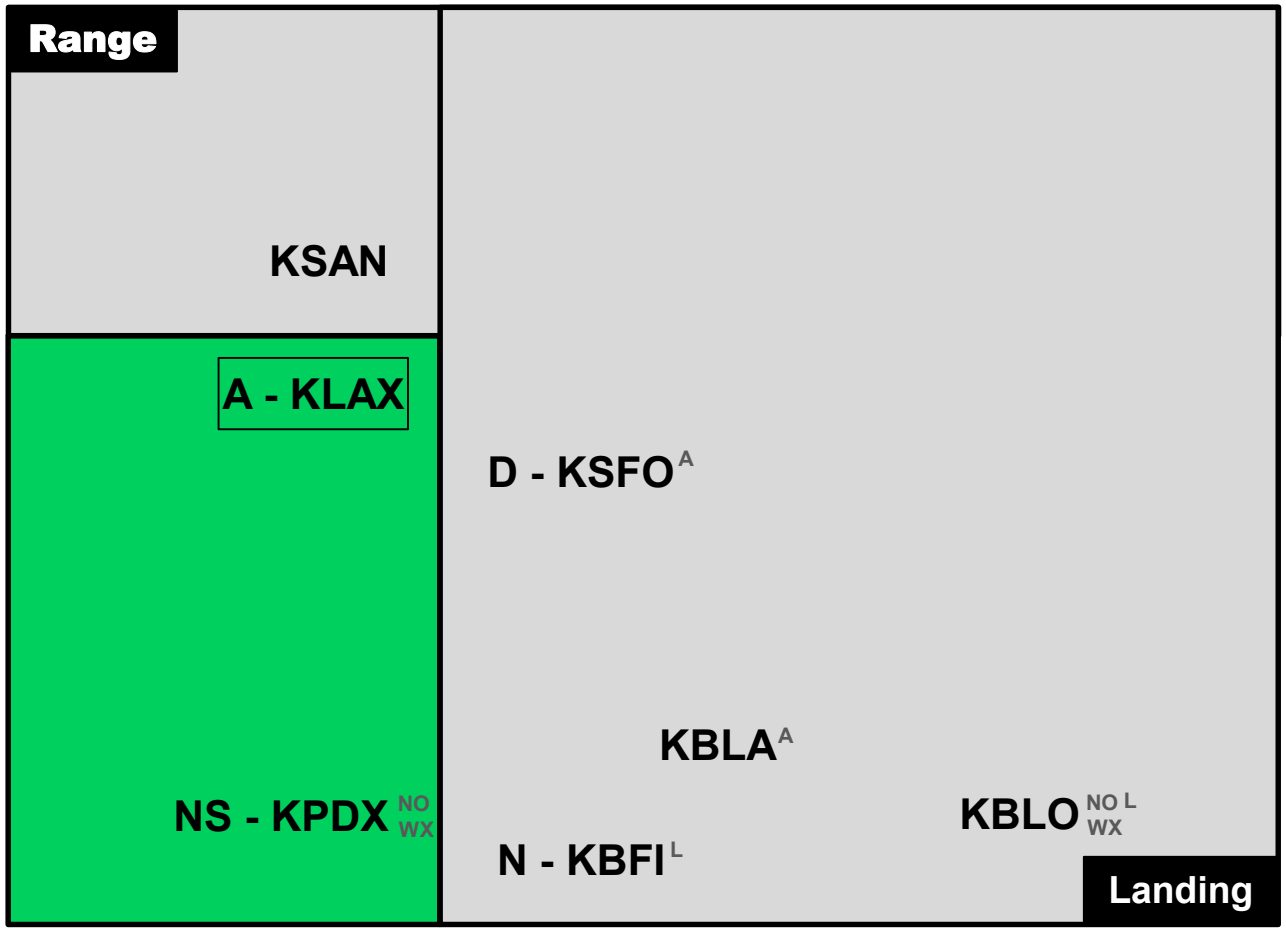
Diversion: KLAX

Basic

Est Lndg Wt	Max ALT	Precision	Approach	Fuel Resrvs	Thrust Rev
200,000 lbs	FL350	0.3	CAT I	3,000 lbs ◂	No ◂

KLAX Alternate

ATIS
LDAAvail., LDReq
Etc.



shorthand 1

CRZ	DES	APP	LAND	TAXI
1	0	0	0	0

Detailed version of 1 – This is the more complete description of item 1